Exhibit 11

NHTSA's RECENT VEHICLE CRASH TEST PROGRAM ON COMPATIBILITY IN FRONT-TO-FRONT IMPACTS

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ABSTRACT

This paper presents results from NHTSA's light vehicle compatibility crash testing program during 2005 and 2006. During these years, NHTSA Research has continued to collect full frontal rigid wall data in conjunction with the U.S. New Car Assessment Program (USNCAP), it has supplemented this with additional rigid barrier data to explore barrier design options, and it has developed and conducted vehicle-to-vehicle crash tests to explore the potential for reducing injuries by improving the crash compatibility between light vehicles. This effort was begun by first identifying the most promising metrics to characterize full frontal crash compatibility using data taken during frontal USNCAP testing, selecting crash test vehicles based on the metrics, and finally, performing full-frontal vehicle-to-vehicle crash tests to evaluate the probability of belted occupant injury and fatality in the crash vehicles. The test series provided evidence that by maintaining structural alignment and matching frontal energy absorptions, the probability of injuries/fatalities in both the Light Trucks and Vans (LTVs) and passenger car can be significantly reduced.

Carmakers are now voluntarily addressing compatibility in the U.S. by aligning their structures and implementing Secondary Energy Absorbing Structures (SEAS) and Advanced Compatibility Engineering (ACE). Vehicle-to-vehicle tests were conducted to understand how these new concepts perform and what sort of additional measures and performance tests may be needed. The results of these tests are presented and discussed in the paper. The advent of SEAS structures also presents challenges to characterize and measure their performance. A new rigid override barrier (ORB) concept has been developed and tested for this purpose. This paper also summarizes and discusses the preliminary design and testing of the ORB.

Finite element studies of vehicle-to-barrier interactions suggest that the axial load cell barriers used prior to 2006 introduced low estimates of force heights on the barrier. In order to understand the error content in previous estimates of force height, several vehicles were crash tested into a high-resolution barrier, which is a 9x16 array of 125x125 mm single-axis load cells, each rated for measuring up to 300kN of compression perpendicular to its face. The results of this crash test program and their implications are discussed in this paper.

INTRODUCTION

In September 2002, NHTSA formed an integrated project team (IPT) to address light vehicle compatibility and in June 2003, the IPT issued its report [NHTSA, 2003]. The proposed initiatives for vehicle strategies were:

Proposed Initiatives:

1. NHTSA will pursue a comprehensive crash test program in an effort to determine whether vehicles of comparable mass, but with considerably differing characteristics (e.g., Average Height of Force – AHOF, initial stiffness, etc.), produce quantifiable injury measurement differences for occupants in the struck vehicle.
2. Using existing fixed rigid barrier crash test data, pairs of vehicles that are comparable in classification (e.g. large SUV), but different in measured characteristics (e.g. high vs. low AHOF) will be identified.
3. Vehicle-to-vehicle crash tests will then be conducted with these vehicle pairs in several configurations to determine whether the vehicle characteristic differences have any influence in the struck vehicle occupant injury outcome.
4. If differences can be quantified, NHTSA will seek to identify countermeasures for potential establishment of compatibility requirements.

Expected Program Outcomes

An expected outcome of this initiative would be to establish a more uniform range of vehicle characteristics within the vehicle fleet. For example, establishing a range (or ranges) for AHOF would lead to improved structural engagement in frontal impacts and would facilitate the design of self protection countermeasures (such as side door beam designs). It may also facilitate improved compatibility with roadside hardware (i.e., guardrails)

Improved energy management between striking and struck vehicles in real world crashes, particularly between passenger cars and LTVs, would be a desired outcome for the longer-range effort. An energy management approach could lead to improved energy sharing in vehicle-to-vehicle crashes. It could also provide the opportunity to improve occupant compartment integrity, there by decreasing intrusion-related fatalities and injuries and improving partner protection."

In December, 2003, the Alliance signed a voluntary agreement between 15 major carmakers to vertically align 100% of the signatory's LTV fleet fronts with passenger cars by 2009 [Alliance, 2003 and 2005]. The agreement defined compatibility in terms of mass ratio, difference in frontal stiffness, and difference in height of frontal structures for sharing crush energy, which is a universal concept of the problem. The agreement identified research to be performed on crush energy sharing and identified two options for the carmakers to accomplish this alignment:

- **Option 1** - Equip LTVs with primary load carrying structures (rails) that overlap the Part 581 bumper zone by 50% or more. This zone extends from 16 to 20 inches above the ground and the passenger cars have their primary structures based on this specification.

- **Option 2** - Equip LTVs with primary structures that overlap the Part 581 zone by less than 50%, but fit these vehicles with secondary energy absorbing structures (SEAS) that fully overlap the Part 581 zone to limit override and better engage passenger cars. These LTVs are typically higher off the ground and have higher rails so they need additional low frontal structures to achieve crash compatibility. A quasi-static test for the Option 2 LTV SEAS structures was also proposed. This was a push test on the SEAS showing that it could resist at least 100 kN of force within the first 400 mm of distance from the front of the rails.

The voluntary agreement was implemented in MY 2004 and, as of November 2006, 62% of applicable LTVs were designed in accordance with the front-front criteria in the agreement [Alliance, 2006]. With this voluntary initiative underway for several years, it is useful to examine the light vehicle compatibility problem to see vehicle structural changes over years from model to model.

COMPATIBILITY METRICS

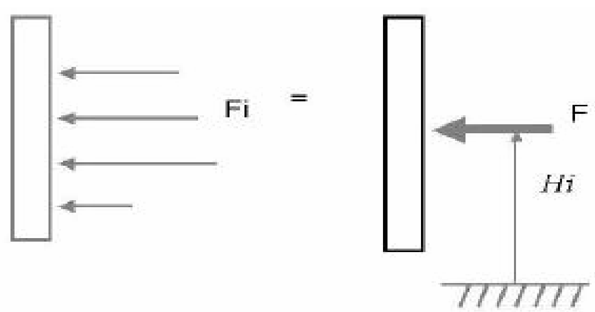
In FY 2004, a compatibility crash test program was performed by NHTSA as called for in the IPT report. However, the LTVs tested in that program were chosen and tested in such a way that little in the way of high injury measures were observed. This result provoked a review of the NHTSA approach to measuring compatibility in 2005 and a review of the test procedures for evaluation.

Research on a test procedure for the passenger cars and option 1 LTVs was begun in 2005 with an evaluation of the vehicle compatibility metrics being researched at various sites and their potential for computation from a rigid barrier test, since this was seen as the only option for a near-term test. The objective behind the metrics was to encourage design of a common crush box at the front of each light vehicle that would have similar structural characteristics and thus create a compatible fleet. The common structural characteristics that were selected were average height of force and frontal stiffness. A metric for the crush energy stiffness and the 400 mm depth of the crush box were selected based upon a DaimlerChrysler concept for frontal compatibility [Nusholtz, 2004], and the NHTSA metric for average height of force was redefined to extend only to 400 mm of crush (it previously went to the end of the crush). The two new compatibility metrics selected for study were:

AHOF400 = average height of force delivered by a vehicle in the first 400 mm of crush,

Kw400 = stiffness related crush energy absorbed by a vehicle in the first 400 mm of crush (also called the work stiffness).

Computation of AHOF400: When a vehicle hits a rigid load cell barrier in a full frontal impact, the individual forces measured on the array of load cells can be used to calculate the height of force (HOF) as a function of crush (d), as depicted in Figure 1 below. Note that the variables in Figure 1 that are a function of the crush are indicated as such by d in parentheses (e.g. F(d)). Each of the forces that hit the load cells at a given time are multiplied by their respective height from the ground (H_i), those forces are summed, and then divided by the sum of all the forces as illustrated in the equation below. In the equation, "n" represents the number of load cells.



$$HOF\ (d) = \frac{\sum_{i=1}^{n} F_i(d).H_i(d)}{\sum_{i=1}^{n} F_i(d)}$$

$$AHOF400 = \frac{\sum_{d=25mm}^{400mm} HOF(d).F(d)}{\sum_{d=25mm}^{400mm} F(d)}$$

Figure 1. Computation of the Height of Force

So, the average height of force (AHOF400) is the weighted average of the HOF values during the first 25 to 400 mm of vehicle crush as illustrated Figure 1. This crush range is used to eliminate the noise in the data in the first 25 mm of crush when the relatively soft bumper is engaging the wall and is limited to a maximum crush of 400 mm to include the forces exerted on the wall by the rails buckling, but stop before the engine contact exerts significant forces. This approach was thought to focus the metric on the average height of all frontal structures in the compatibility crush box at every step in the crushing process without undue focus on the rails alone.

The data to compute AHOF400 were the net forces on each of the axial load cells in the rigid barrier (F_i in Figure 1). Since the data analysis assumed that these forces were located in the center of each cell, the error in the location of each cell net force could be as much as ½ of the cell dimension. Consequently, a barrier made up of large load cells had a larger error than one made up of smaller load cells. This effect will be examined further in barrier crash tests described below.

Computation of Kw400: The stiffness metric based on crash energy is derived from equating the energy stored in an ideal spring (1/2 K x^2) to the work of crushing the vehicle front end (∫Fdx), as shown in the equation below. Again, the integral of the area under the force-deflection curve was evaluated between 25 to 400 mm of vehicle frontal crush to be consistent with the compatibility crush box concept and AHOF400. Here, if there was a lot of area under the force-deflection (F-d) curve, then a lot of work needed to be done to crush the vehicle front. In other words, high F-d area meant high crush work and high stiffness. When a high stiffness vehicle strikes a low stiffness vehicle, most of the crash energy will go into the low stiffness vehicle and its front end will deform the most in absorbing this energy. An example of this is when a high stiffness LTV strikes a soft passenger car, the car is grossly crushed and the occupants severely injured, while the LTV occupants often walk away. This result is a combination of stiffness ratio and mass ratio effects, both of which work against the car occupants.

$$\text{Kw400} = \frac{2\int_{25mm}^{400mm} Fdx}{\left(400^2 - 25^2\right)}$$

Examples of the source data collected in conjunction with the 2005 USNCAP rigid barrier frontal crash testing and how these metrics fit the data are shown in Figures 2 and 3 for a 2005 Chevrolet Trailblazer.

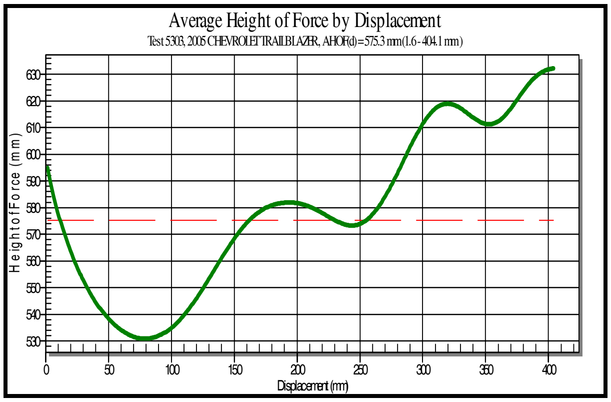


Figure 2. NCAP Test # 5303, Average height of the total force as a function of displacement (crush). The dashed line shows AHOF400

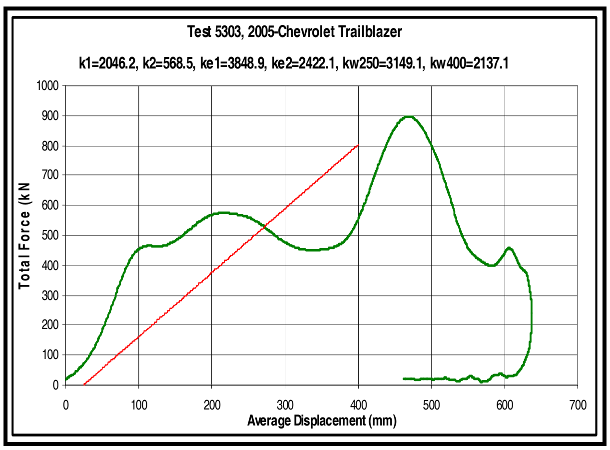


Figure 3. NCAP Test # 5303, Total force as a function of displacement (crush). The straight solid line shows the idealized Kw400 spring stiffness

Figure 2 shows a typical height of force data plot for a modern sport utility vehicle (SUV). Note the value of AHOF400 at about 575 mm, which is indicated by the horizontal dashed line in the figure. This value is a good deal above the typical passenger car (see Figure 4). Another point is that these curves often start very high, at 600-700 mm, and then drop rapidly downward to give an overall average around 550-600 mm. In such cases, the AHOF400 value may be misleading as a predictor of structural engagement. This is true because, when two vehicles strike each other in a full frontal crash, the first part of the structures that engage will determine the subsequent progress of the engagement. Thus, if the LTV has a high structure in front of the rails and the passenger car has a low, then an override may ensue, regardless of how low is the rearward LTV structure, including the rails. In fact, we observed such a case when we tested a Civic-Silverado crash pair, which will be discussed below. The benefit about height of force data is that it does a good job of capturing all the structural interactions that lead to structural engagement, not just the rails.

Figure 3 shows the force-deflection data for the 2005 Chevrolet Trailblazer. The K values listed in the header are the various stiffness metrics that were investigated and discarded during the year, with the Kw400 value shown at the far right, and as a solid straight line in the plot. There are typically two peaks in these plots – the first is the rails buckling (about 200 mm in Figure 3), and the largest peak is the engine striking the wall (about 460 mm in Figure 3). Because an engine peak adds so much area to the Kw400 computation (through high force to the wall or partner vehicle), this metric can be used to keep the engine back from the front of the vehicle and also ensure that the rail peak does not get too high, which would come from rails that are too stiff.

When Kw400 and AHOF400 are combined with mass ratio, a complete set of compatibility metrics is created to evaluate the benefits of matching frontal structures. This evaluation was begun with an analysis of the dispersion of the metrics in the fleet.

<u>**Compatibility Metric Values in the Fleet**</u>: The following three figures show the dispersion of the compatibility metrics among vehicles in the fleet. Figure 4 shows a scatter diagram of AHOF400 in model year (MY) 2000-2005 light vehicles tested in the frontal USNCAP program. Figure 5 shows Kw400 for these vehicles. Finally, Figure 6 shows the cumulative distribution of mass ratio in frontal crashes over the last 10 years of the U.S. National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) crash data.

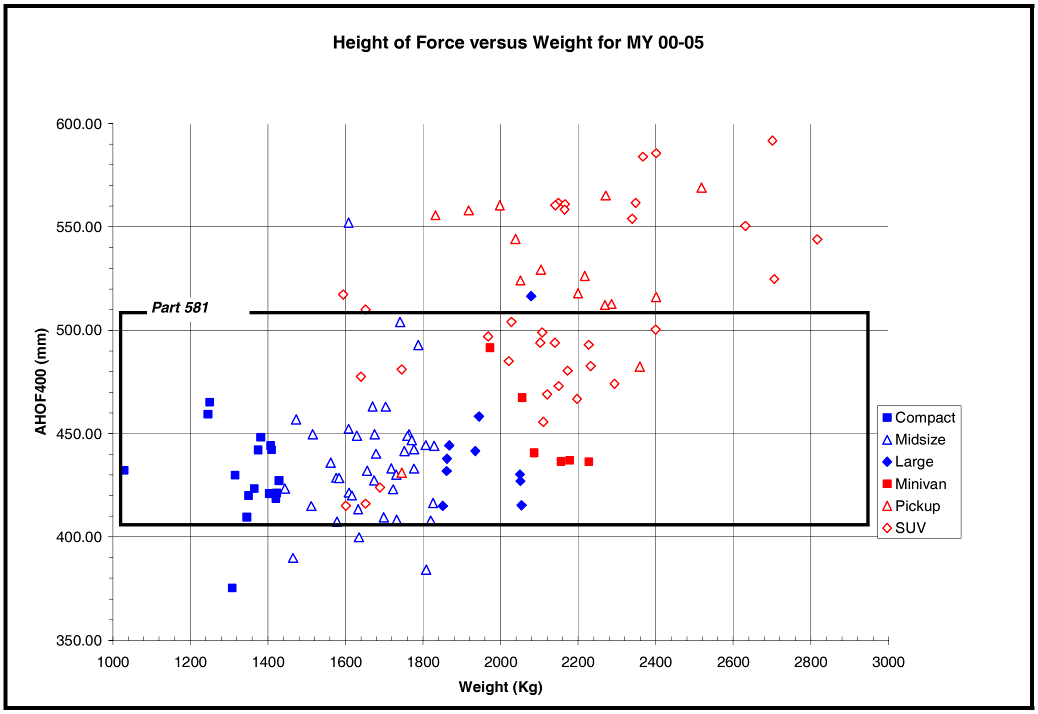


Figure 4. AHOF400 versus vehicle test weight, MY 2000-2005

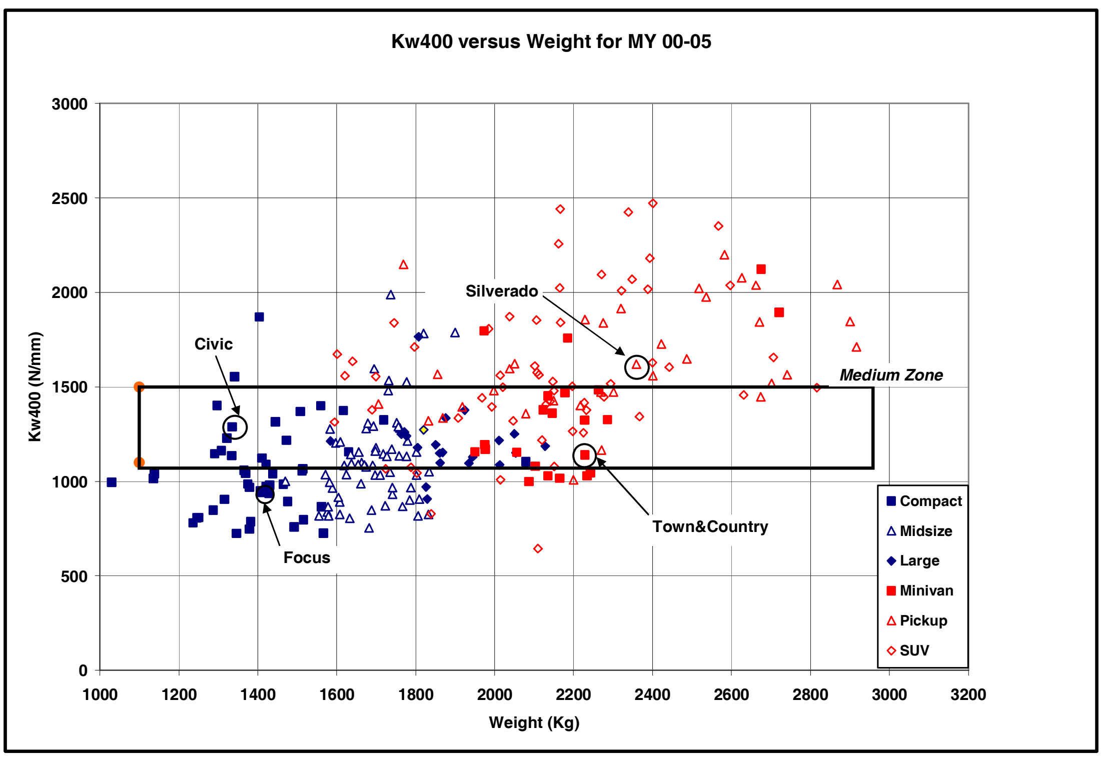


Figure 5. Kw400 versus vehicle test weight, MY 2000 - 2005

The height of the Part 581 bumper zone is shown in Figure 4, along with the modern fleet data for AHOF400, plotted as a function of test weight. The Part 581 bumper zone is 16-20 inches above the ground, or 406-508 mm, as established by NHTSA federal regulation. This zone has been defined by NHTSA as the compliance zone for low speed bumper tests to ensure that light vehicle passenger car bumpers match up and low speed damage is minimized. This zone has also been proposed by the industry as a compliance zone for the height for delivery of forces of LTVs [Alliance, 2003 and 2005]. In order to prepare for problem definition and benefits analysis, the Part 581 zone was defined as the "medium" value of AHOF400. AHOF400 values below this were low, and those above were high. The approach was to evaluate the potential benefits of moving all vehicles into the medium AHOF400 zone by comparing the injury results from vehicle crash pairs with one or more vehicles outside the zone to pairs with both vehicles inside the zone.

In Figure 5, the values of Kw400 are shown for the USNCAP vehicles tested during MY 2000-2005 as a function of weight. Here the medium range, 1100-1500 N/mm, was chosen as a best compromise between values in passenger cars and LTVs, also acknowledging that some of the heavier LTVs should be included so that real world frontal structural designs of medium stiffness at higher weights would be possible. The approach was to evaluate the potential benefit of moving all the vehicles into the medium Kw400 zone by comparing crash performance of vehicles outside the medium zone to those inside the zone. At this time, it is assumed that the most desirable condition is when all Kw400s move into this zone and all vehicles thus are able to more equally share crash energy. However, more research is needed to demonstrate that energy compatibility matching does not have a negative effect on self-protection and if it is the optimal metric to use for energy compatibility.

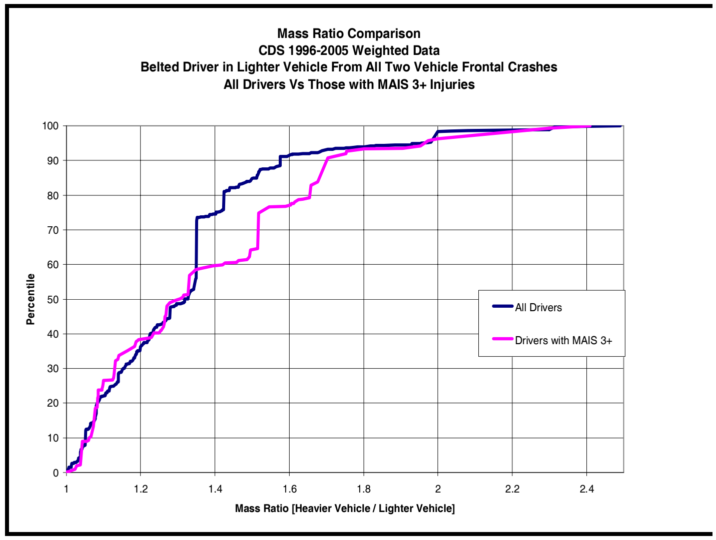


Figure 6. Cumulative distribution of mass ratios in CDS data for light vehicle frontal crashes, MY 1996-2005

In Figure 6, the cumulative distribution of weight ratios in the most recent 10 years of light vehicle frontal crashes in CDS data are shown. These data show that a mass ratio of 1.67 is at about the 93rd percentile for all two vehicle frontal crashes as well as those resulting in MAIS 3^{+} injuries. At mass ratio of 1.67 (and below) it could reasonably be expected that structural characteristics should be very important for controlling injury outcomes. In fact, the working hypothesis at the outset of FY 2006 was that structural height and stiffness matching could be used to overcome mass ratio effects up to this level and reduce injury outcomes compared to unmatched vehicle pairs.

RIGID BARRIER TEST DATA AND METRICS RELIABILITY ANALYSIS

Nearly all of the rigid barriers that have been used in conjunction with the USNCAP testing have collected axial force data from a matrix of load cells that is 4 rows of 9 columns using 250x250 mm load cells. A few of the barriers had a matrix of 2x3 load cells and fewer still were 9x18. Consequently, a series of crash tests was performed using a high resolution axial barrier (9x18 load cell matrix measuring axial force alone) for comparison to the original data collected during USNCAP from a 4x9 array. This was done to assess how repeatable the metrics were for these aged vehicles and how much AHOF400 might change as a function of barrier resolution in the tests. The results of this research are shown in Table 1 below.

Table 1. Comparison of metrics computed from key tests

NCAP Barrier Data			4x9 Matrix		
	Test No.	Shift (ms)	Kw400 (N/mm)	AHOF400 (mm)	Test Weight(kg)
02 Focus	4216	1.3	934	436	1410
01 Civic 2Dr	3456	-0.1	1265	412	1335
05 Town&Country	4936	1.9	1137	476	2229
03 Odyssey w/o ACE	4463	-2.1	1448	443	2178
03 Silverado	4472	3.1	1619	475	2359
05 Odyssey with ACE	5273	2.0	1456	450	2263
03 Accord	4485	1.3	1027	429 (2x3)	1571
96 Dodge Caravan	2997	0.75	1172	470	2011
High Res Barrier Data			9x18 Matrix		
2006 Test Series	Test No.	Shift (ms)	Kw400 (N/mm)	AHOF400 (mm)	Test Weight(kg)
02 Focus	5712	0.9	947	460	1410
01 Civic 2Dr	5710	0.7	1261	382	1582
05 Town&Country	5713	1.0	1124	463	2354
03 Odyssey w/o ACE	5144	-0.15	1360	467	2146
03 Silverado	5711	1.0	1472	511	2273
05 Odyssey with ACE	5714	1.5	1542	457	2388
2004 Test Series					
04 Accord	5062	1.5	1027	508	1624
96 Dodge Caravan	4990	0.8	1163	475	1976

The first thing to notice about Table 1 is the column labeled "Shift, ms." The data entered in this column are the amount of time, in milliseconds, that the force data needed to be time-shifted by hand so that the force-deflection curve passed through (0,0). This effect showed up in Figure 3, where the F-d curve did not go through (0, 0). If this time shifting is not done, then the Kw400 could be as much as 10% in error because the area under the F-d curve from 25-400 mm is inaccurate. The need for this shift comes from the test procedure to trigger force data collection, which was done by contact tape on the vehicle bumper. This data collection was triggered separately from the accelerometer data used to compute the displacement. Later, when the data was filtered to smooth out the noise, some rounding in the force-displacement curve took place near (0, 0). For the time being, it was assumed that like causes created like effects (smoothing, etc., would affect all the curves similarly), and, for research purposes, before computing Kw400, initial data were adjusted to start the F-d curve through (0,0).

The second thing to notice about Table 1 is the values for Kw400. Here, the shaded values for Kw400 did not seem to be affected by barrier resolution, the age and use of the vehicles, or test weights. Of particular interest on the latter point are the Honda Civic and the Town & Country. These two vehicles were tested at significantly higher weights in the high resolution barrier tests, yet they showed nearly the same Kw400 values. However, the unshaded Kw400 values tell a different story for the other vehicles. These vehicles do show an increase of Kw400 with weight. The likely explanation of these data is that it depends on where the weight is placed and what it does. If this weight occurs in the crush box and comes from bigger rails, then it will likely also contribute to a higher stiffness of the vehicle. A final point on this is that we have no good estimates of the amount of manufacturing variability for Kw400 of a given vehicle model. Further, this is confounded by age and use of these vehicles. Thus, we should not expect exact agreement between new vehicle tests and tests of used vehicles several years old.

The data for AHOF400 in Table 1 show consistent trends with the variations in test conditions, especially weight. That is, the Focus and the 03 Honda Odyssey were tested at nearly the same weights. In both cases, the AHOF400 changed significantly from the 4x9 to the 9x18 tests, which was expected with the change to a higher resolution barrier and reducing the AHOF400 error as discussed before in Figure 1. Similarly, the Accord AHOF400 showed a great deal of motion upward in moving from a 2x3 barrier to the 9x18 barrier. However, the Civic and Town & Country were tested at higher weights in the 9x18 tests and their AHOF400s moved down, just as expected with the added ballast. The rest of the tests moved up or down depending on the test weight.

FULL FRONTAL VEHICLE-TO-VEHICLE CRASH TEST SERIES

Part I – Option 1 LTVs and Passenger Cars

The vehicle-to-vehicle crash test program in FY 2006 was designed to complete the IPT series for vehicle-to-vehicle crash testing. Specifically, it was designed to complete a set of full frontal car-LTV crash tests to determine injury outcome differences due to different vehicle characteristics. Further, it was desired to investigate the ability of stiffness matching to overcome a fairly high mass ratio for vertically aligned structures. The LTVs in this part

of the test program were all Option 1 LTVs (no override protection necessary), chosen with comparable mass but of differing model types such as pickups, SUVs, and minivans. The vehicles were all chosen with similar AHOF400 to achieve vertical alignment, though this was visually checked prior to testing by alignment of the rails. Ballasting of the LTVs and passenger cars was used to maintain a constant mass ratio across all tests and the tests were all conducted at the same closing speed, thus allowing the results to be directly compared for the single variable of frontal stiffness as measured by Kw400.

This testing was implemented under very severe test conditions (high mass ratio and high closing speed), following the reasoning that if significant injury improvements can be shown under these conditions, then injury improvements should show up at lesser conditions as well, though perhaps not in a uniformly distributed manner. However, if injury improvement did not show up at the severe conditions, then perhaps it's not really there, which was suggested by the injury outcomes from the 2004 IPT test series. Again, the testing goal was to overcome the large crash energy in a high speed, high mass ratio test using frontal structural matching alone.

The vehicles for the test series were selected from data such as that shown in Table 1 and Figure 5. The aggressive pair was the 2002 Focus-2003 Silverado. This pair was aggressive in the sense that it had the highest stiffness ratio (LTV/car = 1.73), and a high mass ratio (1.67). The compatible pair was chosen to be the 05 Town & Country-2001 Civic 2Dr with a stiffness ratio of 0.90, with the Civic ballasted to the Focus weight and the Odyssey ballasted to the Silverado weight. How close the stiffness ratio needs to be to 1.0 for true compatibility is a matter to be determined by further research. However, inspection of Figure 5 shows that stiffness ratios much higher than those tested are easily possible.

Height-aligned vehicles were chosen throughout this part of the test program in order to investigate the effect of frontal stiffness on injury outcomes without confounding the stiffness results with height variations or override conditions. This was deemed important because the industry was already voluntarily aligning LTV frontal structures to match passenger cars with full compliance planned in 2009 (Alliance, 2005). The results of these tests would give an indication of how much additional benefit gain is possible through energy matching after the voluntary alignment is complete. The selection of test vehicles was made on the basis of AHOF400 being well inside the Part 581 zone (Figure 4). Once purchased, the rail structures on all vehicles were measured and visually inspected to gage a good structural alignment as shown in Figure 7 below.

Figure 7. Vehicles with rail structures aligned

The mass ratio selected for the test was 1.67, which is at the 93rd percentile of all CDS frontal crashes (Figure 6). Ballasting was then employed in the test vehicles as necessary to maintain the weight of the target car at the same value for all crashes, and the weight of the bullet LTV at the same value for all crashes. Thus, frontal height and mass ratio were maintained as close as possible for all tests while varying the frontal stiffness as measured by Kw400.

All vehicles were run with belted Hybrid III 50th percentile male drivers and belted Hybrid III 5th percentile female passengers in the right front seat. All dummies in both bullet and target vehicles except passenger dummy in bullet vehicle were fitted with Thor-Lx legs so lower extremity injury measures could be taken.

Ford Focus-Chevrolet Silverado Test

The first pair tested was a Focus-Silverado pair, which was chosen because it was thought to be an aggressive pair in terms of stiffness (Figure 5). The target vehicle was a 2002 Ford Focus with a Kw400 of 947 N/mm. The bullet vehicle was a 2003 Chevrolet Silverado with a Kw400 of 1619 N/mm. This pair was used to determine the closing speed for all subsequent testing.

The speed of the test series was desired such that the aggressive LTV/car pair would produce a probability of severe to fatal injury levels in the dummies of the target vehicle. This was done by running tests at three different closing speeds of 70, 75, and 80 mph between the Silverado and Focus. The injury results for this series are shown in Figures 8 and 9 below, overlaid on the probability of injury curves that were used in the preliminary economic analysis for the most recent FMVSS No. 208 upgrade.

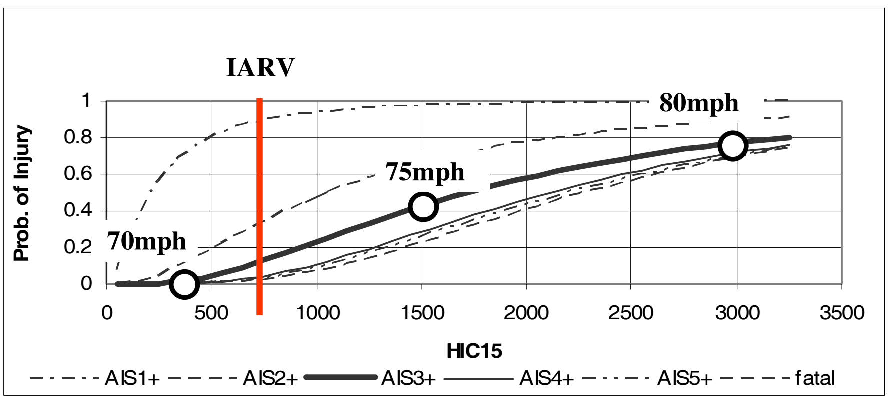


Figure 8. Probability of AIS 3+ head injury for the Focus driver (50th M)

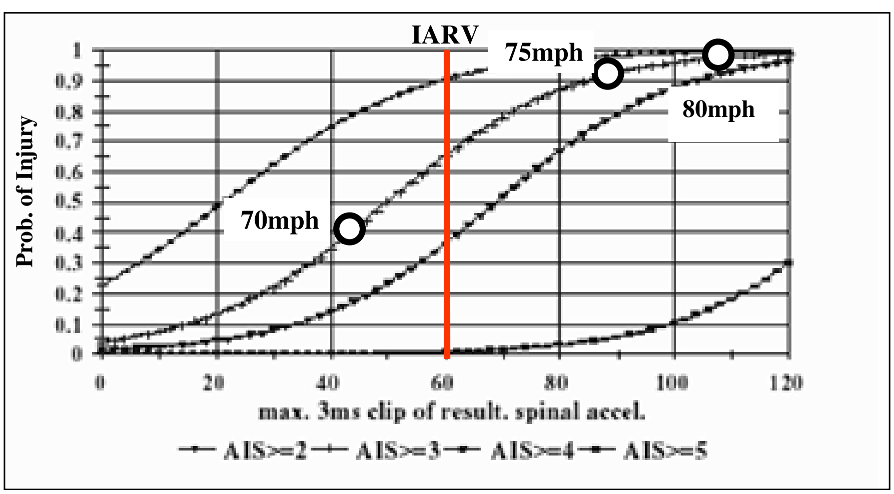


Figure 9. Probability of AIS 3+ chest acceleration injury for the Focus driver (50th M)

Figures 8 and 9 also have overlaid on them the Injury Assessment Reference Values (IARVs), which the agency uses to determine pass/fail in FMVSS No. 208 compliance tests. In addition, the Focus driver injury results are shown as circles on the figures for the three tests conducted. Though many injury measures were taken in these tests, only two showed the most consistent results across all crash conditions. These were the 15 second Head Injury Criteria (HIC15), and the chest acceleration (3 millisecond clip).

Since the Silverado/Focus vehicle pair was chosen as the aggressor pair for this test program, the test speed selected for all the tests needed to be high enough that severe injury measures in the Focus driver dummy could be expected. This requirement was interpreted to mean that the Focus driver injury numbers should be slightly over the IARV values. In this way, if structural matching worked, then the Focus driver injury values for head and chest would move below the IARVs, back into the acceptable zone for injury risk. Thus, Figures 8 and 9 show that 75 mph should be chosen as the closing speed for all vehicle-to-vehicle crash testing in the FY 2006 test series. At this closing speed and these mass ratios, the delta V on the target passenger car was approximately 46 mph (76 kph). Figure 10 shows where this delta V falls with respect to the average annual CDS data for frontal crashes.

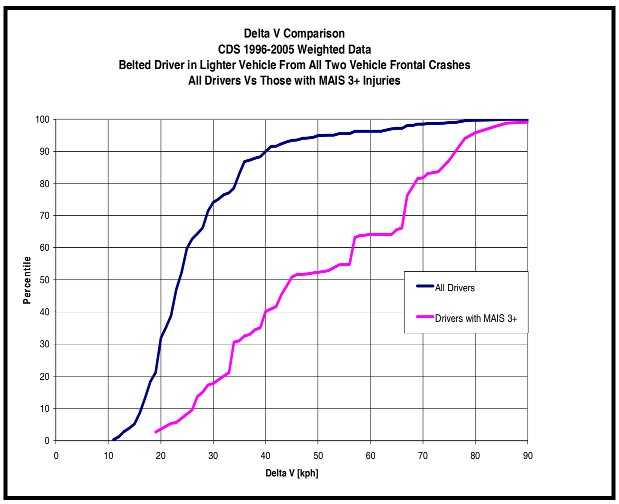


Figure 10. DeltaV distribution for the lighter vehicle in frontal crashes, CDS data 1996-2005

Figure 10 shows that the test condition for a smaller-vehicle delta V of 75 kph was at about the 98th percentile of all two-light-vehicle, belted-drivers, in frontal crashes. Further, when the subset of these crashes at the higher severity of MAIS 3^{+} is considered, the delta V is at about the 87th percentile. This condition is reasonably extreme and thus meets all the test program design criteria for severity and injury outcome.

<u>Ford Focus-Option 1 LTVs Comparative Test Series</u>

With the test conditions determined, a series of crash tests was performed to compare various LTV frontal stiffness and construction methods. In particular, test data was desired for LTVs constructed with body-on-frame types and a new LTV construction called Advanced Compatibility Engineering (ACE) strategies by Honda. For all of these tests, the 02 Focus was used as the target. The results of this crash test series are shown in Table 2.

Table 2. Probability of Fatality in Belted Focus Driver. 75 mph closing, mass ratio 1.67, aligned structures, HIII 50th M

	Kw400 N/mm	**Focus Driver Head (HIC15)**	**Focus Driver Chest (Chest G)**
02 Focus	934		
Bullet Vehicles			
05 Town & Country	1137	17% (1267)	2% (72)
03 Odyssey (no ACE)	1448	30% (1689)	5% (90)
05 Odyssey (ACE)	1456	41% (1951)	5% (90)
03 Silverado	1619	25% (1482)	5% (88)

Table 2 shows a high HIC15 and a high probability of fatality in the Focus for all tests performed in the comparative series - all these LTVs are aggressive crash partners for the soft Focus. According to Honda, ACE construction method adds several significant load paths for crash energy to follow in addition to the usual one through the rails in order to distribute the crash energy more efficiently compared to more typical body-on-frame construction. However, our test results show that this more efficient frontal structure magnified the Kw400 difference to produce a higher injury outcome than the previous version of the 03 Odyssey, which did not have the ACE structure, but did have nearly the same Kw400 value.

Option 1 LTV Stiffness Matching Test

The next crash test was based on finding a matched compatible pair for comparison (Figure 5). A medium compact car was selected to replace the Focus, which was the 01 Civic 2 door, and a medium LTV was selected to replace the Silverado, which was the 05 Town & Country. Again, ballasting was used to maintain the mass ratio, the test was run at the same closing speed, and the matched heights of the structures were checked visually. The crash results for this test are shown in Table 3.

Table 3. Probability of Fatality in Belted Civic Driver. 75 mph closing, mass ratio 1.67, aligned structures, HIII 50th M

	Kw400 N/mm	Civic Driver Head (HIC15)	Civic Driver Chest (Chest G)
01 Civic 2 door	1265		
Bullet Vehicle			
05 Town & Country	1137	4% (802)	1% (66)

Comparison of the results for the crash tests with the 05 Town & Country shown in Tables 2 and 3 demonstrate potential improvement in injury outcomes for the compact car driver when the Kw400 is matched to the striking LTV. A further result in this area stands out when the injuries to the belted LTV driver are also compared, which is done in Table 4.

Table 4. Probability of MAIS 3+ injury in belted LTV Driver. 75 mph closing, mass ratio 1.67, aligned structures, HIII 50th M

	LTV Driver Head (HIC15)	LTV Driver Chest (Chest G)
Kw400 Aggressive Pair 02 Focus – 03 Silverado	3% (435)	45% (45)
Kw400 Matched Pair 01 Civic 2Dr – 05 Town & Country	0% (267)	26% (34)

Table 4 shows the surprising result that injuries went down in the LTV when the stiffness was matched to the compact car. Note that these injuries are at the lesser level of MAIS 3^+ since there was an insignificant probability of LTV driver fatality in any of the compatibility tests conducted in FY 2006. This result came from lowering the stiffness of the LTV from that of the Silverado (1619 N/mm) down to the Town & Country (1137 N/mm), while simultaneously increasing the stiffness of the target car to match. When this was done, the probability of injury in both vehicles went down.

Thus, the goal of the test protocol to overcome the high input crash energy through height and stiffness matching alone was not quite accomplished, but the injury improvement in target and bullet vehicles from unmatched to matched stiffness in terms of head and chest injury metrics was remarkable. Note that all the tests in Table 2 were unmatched pairs, yet making much of the relative ordering of the tests in Table 2 by injury results is premature due to uncertainties in the test procedure and metrics computation as discussed in conjunction with Table 1. Furthermore, the injuries reported in Tables 2 and 3 were due to the full crush event, but the Kw400 metric is only for the first 400 mm of crush. The fact that the matched metric resulted in the lowest injury scores for these severe tests is interesting and adds support to the same result for low speed matched pairs in the CDS analysis discussed elsewhere (Smith, 2006).

Part II – Option 2 LTV Evaluations

NHTSA designed, built and tested a prototype override barrier (ORB) for dynamic testing of LTVs with override protection in FY 2006. Either some sort of override barrier, or a car-like moving deformable barrier (MDB), are the only concepts that can test all presently known types of override-controlling frontal structures. Fixed deformable barriers cannot test the rail extensions that GM is now deploying on the 2007 Silverado, but preliminary results from Europe seem to indicate that they might be able to test the blocker beam structures now being deployed, such as on 2007 Ford F-250 pickups. The ORB can test both. In 2006, NHTSA used finite element models to evaluate ORB test conditions and create data for prototype test design. Vehicle-to-vehicle crash tests were performed on the 2006 Honda Ridgeline and the 2006 Ford F-250 SEAS. In addition, barrier crash tests with these two vehicles were performed with a prototype ORB.

The emergence of SEAS in 2004 on large LTVs caused a great deal of confusion in developing a vehicle dynamic test. There seems to be no clear way forward among researchers, no doubt in part because the various fleet examples of SEAS are so different. One thing is clear however, the performance of all the different types of SEAS frontal structures cannot be evaluated with a full face rigid barrier test, so a new test is needed. The most promising evaluation concepts are either a deformable barrier test of some kind, or a low rigid ORB designed to engage and deform the SEAS to measure its strength in a dynamic test. While other organizations evaluated deformable barrier concepts, NHTSA focused on the ORB in 2006.

The ORB test design objective was to create data that can be used to compute Kw400 for the SEAS structures. This is important in that the industry voluntary test for the SEAS [Alliance, 2005] is a quasi-static push test that requires the SEAS structure to withstand a minimum of 100 kN of force before 400 mm deflection from the front of the primary structure (e.g., the rails on which it is mounted). Such a test may guarantee a minimum strength, but this does not prohibit the structure from being designed too strong for good car compatibility. On the other hand, a Kw400 evaluation could make the SEAS compatible, just as could be done for the full frontal test for option 1 LTVs. In order to understand these frontal structures, a small vehicle-to-vehicle crash program was performed in FY 2006. There are of two main types of SEAS at this time: the so-called "blocker beams" that are cross members mounted below the rails, and rail downward extensions at or near the vehicle front without cross members. A common example of each type was tested.

F-250-Focus Test

For the blocker beam tests, the 2006 Ford F-250 pickup was selected. This vehicle was tested against the 2002 Focus with the closing speed adjusted to create the same delta V on the Focus as the other tests so the injury results in the Focus could be compared to the other tests, even though the F-250 is a much bigger and heavier vehicle compared to the option 1 LTVs tested previously. Thus, the closing speed in these tests was 69 mph, with a Focus delta V of 46 mph as before. The F-250 was tested with its blocker beam in place and with the beam removed to see how much difference this blocker beam makes in injury numbers. The results are shown in Table 5 below.

Table 5. Focus driver probability of fatality and injury values in F-250 tests

	06 F250-02 Focus With Blocker Beam	05 F250-02 Focus Without Blocker Beam
Focus Driver (50^{th} M) **Probability of Fatality (Injury measure)**	**Head 10%** (HIC15 = 1023) **Chest 5%** (chest G = 86)	**Head 25%** (HIC15 = 1583) **Chest 10%** (chest G = 99)

Table 5 shows that the blocker beam clearly makes a big difference in injury outcomes for this crash pair. Further, of all the vehicle-to-vehicle crash tests run for compatibility in FY 2006, the probability of Focus driver fatality with the blocker beam is only bested by the match between the Civic and Town & Country (Tables 2 and 3). All other tests had worse outcomes for the Focus driver.

Ridgeline-Focus Test

The other type of SEAS now being deployed by the industry is added structure at the bottom of the rails. For example, the 2006 Ridgeline has downward rail extensions at the front to better engage passenger cars, with unibody construction. The test was run at the same test speed and Ridgeline was ballasted to the same weight as the Silverado in the Focus-Silverado tests so the results could be compared. The results of this test are shown in Table 6 below.

Table 6. Focus driver probability of fatality and injury measures in the Ridgeline test

	02 Focus-06 Ridgeline
Focus Driver (50^{th} M)	**Head 90%** (HIC15 = 3448)
Probability of Fatality (Injury Measure)	**Chest 15%** (Chest G = 106)

The injury measures in the Ridgeline test were by far the greatest in all of the FY 2006 compatibility test series. These high injury values suggest that the Ridgeline SEAS structure was stiffer. This result calls for further research to evaluate how such SEAS structures work, and especially to

develop a prototype ORB test to measure their strength.

PROTOTYPE OVERRIDE BARRIER TESTS

The ORB concept allows an Option 2 SEAS equipped LTV to override the low rigid barrier so that the SEAS can be directly engaged and tested. The concept that was developed for preliminary testing is shown in Figure 11 below.

Figure 11. Final assembly of the ORB with a supporting load cell wall behind it

The current ORB prototype is adjustable in height, width, and depth. It has a single row of 250x250 mm load cells mounted on individual plates at the end of the I beams extending 500 mm from a rigid wall to measure the forces exerted on it. The height of the top of the ORB load cells is adjustable from 16-20 inches (406-508 mm) from the ground. The ORB load cells (including the wood facing block) extend 500 mm forward of the back-wall load cells. When the LTV SEAS strikes this barrier, force-deflection data can be generated that can be used to compute Kw400 values for the SEAS structure. The preliminary determination of test speed was done with finite element modeling.

The F-250 was planned for the initial ORB test since it performed so well in the IPT test series conducted earlier, and since the data from the F-250 ORB test will be used to validate a finite element model of the vehicle. This model was built from a tear-down study performed in conjunction with FHWA, who also want to use it to study roadside safety features.

It would have been best to have the F-250 model to use in simulation of an ORB test and select the test speed. However, the tear-down study to build the model was not complete at the time the model was needed. Further, the data collected from the first ORB tests would be used to validate the F-250 model that was then being built. In other words, the test speed could not be selected using an F-250 model because it was not ready, and it would not be ready until the model could be validated with the data. The approach to this problem was to take the virtual blocker-beam SEAS from the F-250 model and mount it to the rail structure of an existing LTV model. A Ford Econoline model was selected for this virtual test series and ballasted to the F-250 weight. This approach is shown conceptually in Figure 12.

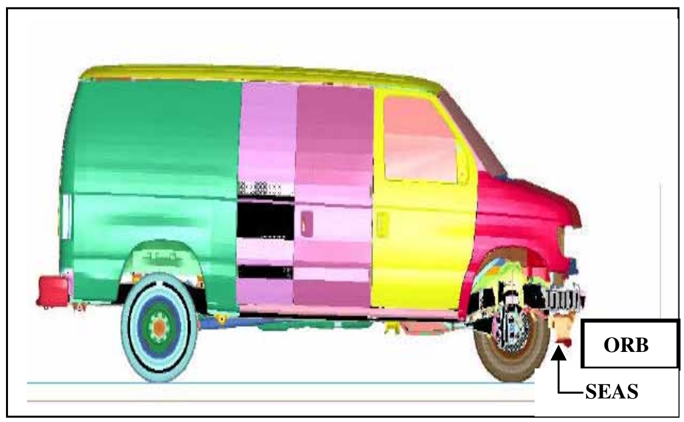


Figure 12. The F-250 SEAS mounted on the Ford Econoline FE model

The rail structure of the Econoline is shown in black in Figure 12 and the SEAS was mounted below it in the same manner as done in the F-250. Clearly, these rails are different from the F-250 rails and this must be considered in the evaluation of the virtual test results. This vehicle model was then impacted into the ORB model in simulated tests at 20 and 30 km/hr, and the results are shown in Figure 13 below. Here, zero displacement was when the ends

of the rails passed over the edge of the ORB. The cross beam was mounted on the rails 100 mm rearward from the end of the rails, which was where the force of deflection began to rise.

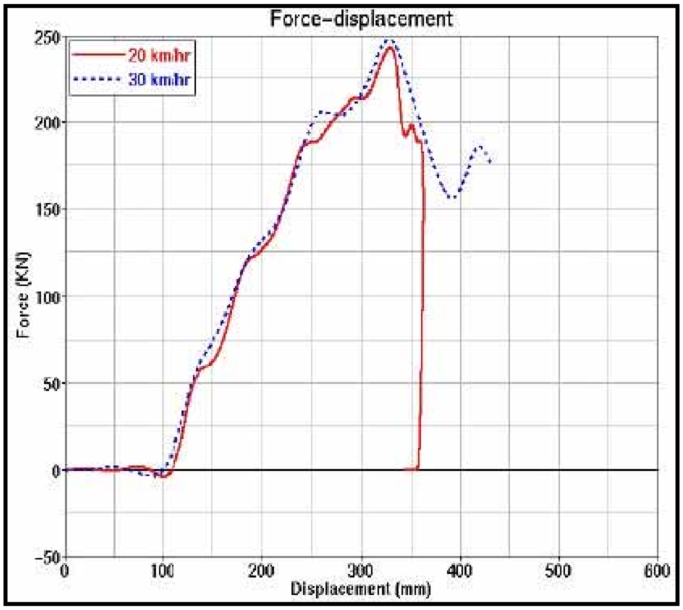


Figure 13. Virtual tests of the F-250 SEAS on the Ford Econoline

Figure 13 shows the two virtual test results that were run for the Econoline with F-250 SEAS to determine test speed. The peak force in these results was nearly the same for both of these tests, but the 20 kph test (12.4 mph) was too slow to create the needed 400 mm of displacement for Kw400 computations. Thus, these results indicate that at least 30 kph (18.6 mph) was needed to achieve 400 mm of crush for this structure. Further, since the F-250 rails are stronger than the Econoline rails, a test speed of 25 mph was selected for the initial F-250 ORB test in the real world.

The strength and performance of the real world prototype ORB was validated by subjecting it to a 25 mph crash using a wrecked car ballasted to the weigh of the F-250 and aligning one of the rails with the end load cell. No damage to the ORB load cells was observed and no load cells were saturated.

The tests of the F-250 and the Ridgeline have been completed, but the results have not been completely analyzed at the time of writing this paper, so they were not included.

CONCLUSIONS

The objective of this test program was to show, in vehicle-to-vehicle crash tests, what improvements might be found through structural matching for compatibility. This structural matching was accomplished using the metrics of AHOF400 and Kw400, the first of these to match height of structures, the second to match energy absorption. These metrics were selected because they could be measured in near-term rigid barrier tests, and they would require no new tests.

For option 1 LTVs and passenger cars, the matched stiffness and alignment crash test pair showed that injury probability fell in both vehicles compared to all unmatched, but comparable, crash tests. However, the test vehicles were chosen close to, or in, the matching zone and very extreme cases have not yet been investigated. Further, more research is needed on how close the stiffness ratio needs to be to one to achieve acceptable injury performance. Also, an injury benefits analysis needs to be completed to understand the real world benefits of the proposed medium compatibility matching zones across the fleet. This work is underway and will be reported elsewhere.

Option 2 LTVs bring in the added SEAS to reduce override of passenger cars. These structures will require a new test, not simply instrumenting a rigid barrier. In 2006, NHTSA researched a rigid override barrier (ORB) as a test concept for option 2 LTVs, with the intent to measure the Kw400 of the SEAS structure so it could be matched to passenger cars just like the Kw400 in a full frontal option 1 LTV test. A prototype ORB was designed, fabricated, and tested. Preliminary testing of this ORB has been completed, but the test results have not yet been analyzed.

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